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ON THE WAVELENGTHS OF ABSORPTION LINES IN QUASI-STELLAR OBJECTS

There are now several quasi-stellar objects in whose spectra absorption lines have been detected. Among the seven objects so far detected with redshifts greater than z = 1.9, five show absorption features. These are PHL 938 (Kinman 1966), 3C 191 (Burbidge, Lynds, and Burbidge 1966; Stockton and Lynds 1966), PKS 1116+12 (Schmidt 1966; Lynds and Stockton 1966; Bahcall, Peterson, and Schmidt 1966), PKS 0237-23 (Burbidge 1967; Arp, Bolton, and Kinman 1967) and PHL 5200 (Lynds 1967). 3C 9 (Schmidt 1965) and PKS 0106+01 (Burbidge 1966) show no traces of absorption features. After the conclusions described by this Letter, based on the first four objects, were reached, and while they were being written up, a preprint concerning the QSO PHL 5200 (Lynds 1967) was received so it has been included here; it contains strong absorption features which appear as broad bands. In this respect it differs from the other objects which show narrow or medium-width absorption lines.

In Table 1 we show the measured wavelengths of all of the absorption features in these QSO's taken from the papers listed above. It is immediately seen that the remarkable feature of these lines is that in many cases there are very close coincidences between the wavelengths measured in different objects. The two objects which show the most lines are 3C 191 and PKS 0237-23. These two objects show thirteen lines which coincide to within 3 Å in the mean. While there are still lines in PKS 0237-23 with no corresponding lines in 3C 191 and lines in 3C 191 for which there are no coincidences in PKS 0237-23, elementary arguments show that the probability that we are dealing with chance coincidences is very small. In the case of the other three objects which show only a few absorptions, each is found to coincide with a feature in the other two objects, when allowance is made for very small differences in wavelength. In the case of PKS 0237-23 I have used the line list of Burbidge (1967).

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This work was completed before I had access to the final line list for this object by Arp, Bolton, and Kinman (1967). It now appears that, while for the stronger lines there is a reasonable agreement in wavelength between the two sets of measures, this is not the case for the weaker lines with $\lambda > 4200^\circ$, and the discrepancies remain to be explained. If we use the list of Arp et al. in Table 1 some of the coincidences are no longer present. Arp et al. have also given a completely different interpretation of the absorption lines, as being due to heavier elements at a redshift of 2.2, close to the emission-line redshift. It is not my intention to discuss these proposed identifications here; they do, however, raise many doubts, both from the spectroscopic standpoint and because a very peculiar composition must be invoked. Regarding the lack of coincidence in the lines with $\lambda > 4200^\circ$, it is possible that some weak absorptions in either set of measures might be due to night sky features. Even so, there still remain a good many coincidences, and the features in the other QSO's in Table 1 are not in question.

This surprising result suggests that whatever the identification of the lines they should be treated as a standard system common to all of these objects, and that the differences between the appearance in the spectra are related to the varying continuum intensities and excitation conditions in the different objects. Unless it can be shown that the lines have a completely local origin this places a different complexion on the nature of the redshifts than has been considered previously. By local origin we mean that they must either be attributed to night sky features or to an absorption feature of local but extragalactic origin. The first of these possibilities can be ruled out by the strength of most of the lines; moreover, they should tend to be stronger in fainter objects, and this is not the case. At the same time the absorption lines cannot be due to interstellar absorption in our Galaxy, otherwise they would appear in stellar spectra; the two strongest lines in PKS 0237-23 look a little like Ca II H and K, but they are well removed from the rest wavelengths of these lines.

Thus we conclude that the standard spectrum must be of extragalactic origin and must either arise in intergalactic matter or be intrinsic to the QSO's in question.

Before considering these possibilities in turn we consider the problem of the identification of the absorption lines, and the redshifts which have been obtained previously. In the case of 3C 191, identifications were made which unambigiously give a value of $z = 1.947 \pm 0.002$ (Burbidge, Lynds, and Burbidge 1966). We have already discussed the case of PKS 0237-23. In the case of PHL 938 Kinman (1966) gave a redshift based on emission features of 1.93. The absorption features at $\lambda\lambda$ 3505, 3535, and 4507, if identified with Si III λ1206.5, Ly-α, and C IV λ1549.1, which appear to be the most probable from the point of view of the spectroscopist, give a mean redshift of 1.907 ± 0.001. However, if we identify them as the features in 3C 191, which are attributed to Si II $\lambda\lambda$1194.1, Si III 1206.5 and Si II 1533.4 and which are slightly closer in wavelength, then the mean value of z is 1.934 ± 0.003. In the case of PKS 1116+12, the two lines measured by Bahcall, Peterson, and Schmidt, the line at λ4570 being less certain, give $z = 1.950$. They measured a possible absorption line at 3648 Å; if due to N V λ1240.1, it gives $z = 1.942$, and hence a mean value of $z = 1.947 \pm 0.003$. Lynds and Stockton measured an absorption line at 3766 Å, which does not correspond with any of the lines given in Table 1. For PKS 0237-23, if we assume that the coincidences with the lines in 3C 191 are due to the same lines as those identified in 3C 191, the mean redshift comes out to be 1.949 ± 0.004.

In the case of PHL 5200, the absorption bands are so wide that we cannot proceed in this way, and central wavelengths have not been published by Lynds. We have therefore estimated wavelengths of the edges of each absorption feature from Lynd's reproduction of his spectra. He identified the strong absorption bands as C IV $\lambda1549$, Si IV $\lambda\lambda1394$, 1403, and N V $\lambda1240$; we give the sharp red edge only of the latter because the violet edge runs into Ly-α. The wavelengths of these edges are listed in Table 1; the range of redshift given by them is 1.98 - 1.89 for C IV, 1.96 - 1.90 for Si IV, and the single edge of N V gives 1.98. The "central" value for C IV is 1.93, and for Si IV, 1.92. A single sharp absorption, identified by Lynds with O I $\lambda1304$, gives 1.979.

Thus our tentative conclusion is that this standard spectrum arises from a region which has a redshift of about 1.95 with a small dispersion about this value. To explain it we can consider the following possibilities:
(1) that all of the objects are observed through an absorbing cloud which is receding at a velocity giving this redshift. Since the objects in question lie in different directions, this would imply on the cosmological hypothesis that, for a short period at the epoch corresponding to this redshift, the intergalactic gas was able to produce the absorption. This possibility requires detailed discussion but it appears, at first sight, to be implausible. Alternatively, we could suppose that the cloud had been ejected from our own Galaxy at this speed (just less than 0.8 c). In this case these absorption features would appear in the spectra of galaxies but there is no evidence for this, so that this suggestion can be rejected.
(2) We could suppose that all of the objects have the same standard redshift. If they were cosmological objects this would be an entirely unreasonable result also. If they are local objects moving at relativistic speed, then

we must suppose that they have all been ejected at the same speed. This is a possible situation, but not a very probable one in my opinion.

(3) We can suppose that the standard redshift is not a Doppler shift. The obvious conclusion is then that it is a gravitational shift, and that the value near $z = 1.95$ is a fundamental value which is determined by the upper limit to the size of the gravitational redshift which is 2 in the classical Schwarzschild solution. However, Bondi (1964) has obtained a limit which is less than this value, though this limit is model-dependent (Chandrasekhar, private communication).

On the basis that the shift is gravitational we can now ask what is the significance of the emission line redshifts which are in all the cases quoted larger than the absorption line standard shift. One possibility is that they are due to gas falling into the massive object inside the region which is giving rise to the absorption spectrum. Alternatively, the whole of the emission line redshift may be gravitational in origin. The very small differences between the absorption line values near 1.95 may be due to random motions of the objects. Except for PHL 938, the values are only of order 1000 km/sec.

It is possible then that they are objects at distances ~ 10 Mpc moving with random motions similar to those of the Virgo cluster galaxies.

It may well be asked whether it is possible to obtain an absorption line spectrum in such a strong gravitational field. The fact that the relative intensities and widths of the lines are not in good agreement with what is expected under normal conditions (Burbidge 1967) and that many lines remain unidentified may be due to the effect of the strong gravitational fields, together with strong radiation and magnetic fields. To obtain a region of comparatively low density near to the Schwarzschild radius it is necessary that one postulates the existence of very massive objects. Thus an object with mass $\sim 10^{12}\ M_{\odot}$ collapsed to a size close to its Schwarzschild radius ($\sim 10^{17}$ cm) may lie inside the whole assembly. Such an object will have a mean density near 10^{17} atoms/cm^3. Since no forbidden lines are seen in the emission spectra of the objects described here, the limits on density set by the appearance of such lines (Greenstein and Schmidt 1964) do not apply in these cases. Since the absorption lines have to be formed between observer and emission lines plus continuum, the emission lines may have added redshifts due to infall into the massive objects.

Obviously many problems remain. What of the bulk of the QSO's which show emission lines with smaller redshifts? Among more than sixty objects with emission line redshifts less than 1.9, one absorption line has been found in BSO 1 (Sandage 1965) at $\lambda 3473$ Å, one absorption feature is present in 3C 270.1 (Schmidt 1966) at $\lambda 3870$ Å, one absorption is found in PKS 1217+12 at $\lambda 4882$ Å, and two in 3C 263 at $\lambda\lambda 6516$, 6568 (Ford and Rubin 1966). The line in BSO 1 is fairly close to a line at $\lambda 3461$ seen in PKS 0237-23, but at the same time, if it is attributed to C IV 1549, the redshift is in good agreement with the emission line redshift (1.241). In the case of 3C 270 the absorption could be C IV λ1549 at a redshift close to the emission line redshift of 1.519, but it also coincides very closely with a line in PKS 0237-23 at λ3866. In the other cases, the lines are outside the wavelength region observed in the objects given in Table 1, but the identifications made by Ford and Rubin give the same redshifts as those from the emission lines. It may be that the absorptions, in the rare cases where they are seen in the objects with $z < 1.9$, are not part of the standard spectrum. However, if one takes the view that the standard spectrum is of gravitational origin then it is tempting to suppose that, despite the spectroscopic difficulties, the redshifts in general are gravitational shifts. Perhaps the objects with smaller shifts are collapsing but have not reached a situation in which an absorption line spectrum can be formed.

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Table 1

WAVELENGTHS (Å) OF ABSORPTION LINES IN OBJECTS WITH $z > 1.9$

Identification[1]	3C 191	PKS 0237-23	PKS 1116+12	PHL 5200	PHL 938[2] (a)	PHL 938[2] (b)
u	3408					
u	3440	3445				
C III 1175.7	3466	3461				
Si II 1194.1	3515	complex 3516-3528				(3505)
Si III 1206.5	3556				3505	(3535)
Ly α 1215.7	3581	3591	3585		3535	
S II 1231.8	3628					
N V 1240.1	3652		3648?			
S II 1255.1	3698					
Si II 1260.7-65.0	3718	3719				
			3766?			
u		3839				
u		3866				
u		3891		3886		
C II 1335.3	3935	3934				
u	3960	3952				
u	3971	3972				
u	4021	4024				
Si IV 1393.8	4109	4116				
				4140-4020[3]		
Si IV 1402.8	4137	4141				
u	4264	4267				
u	4284	4286				
u	4299	4301				
Si II 1526.7	4502					
Si II 1533.4	4519					(4505)
C IV 1549.1	4566	4572	4570	4620-4470	4505	
u		4596				
u		4613				
Mean redshift						
absorption	1.947	1.949	1.947	1.90 - 1.98	1.907	(1.934)
emission	1.953	2.224	2.118	1.90 - 1.98	1.93	

Footnotes to Table 1

(1) Identifications are those made originally for 3C 191. "u" means unidentified in either 3C 191 or PKS 0237-23 (see Burbidge 1967).

(2) In columns (a) and (b) we give two possible sets of identifications and redshifts. That in (a) is the most probable from the spectroscopic standpoint, but we give (b) because this gives a closer coincidence in wavelength.

(3) This broad feature has been identified by Lynds as a blend of Si IV $\lambda\lambda 1393.8, 1402.8$, and thus it has been put between the lines which are identified as those two lines in 3C 191 and PKS 0237-23.